Active serpentinization in the Santa Elena Ophiolite (Costa Rica) as a testbed for in-situ carbon storage

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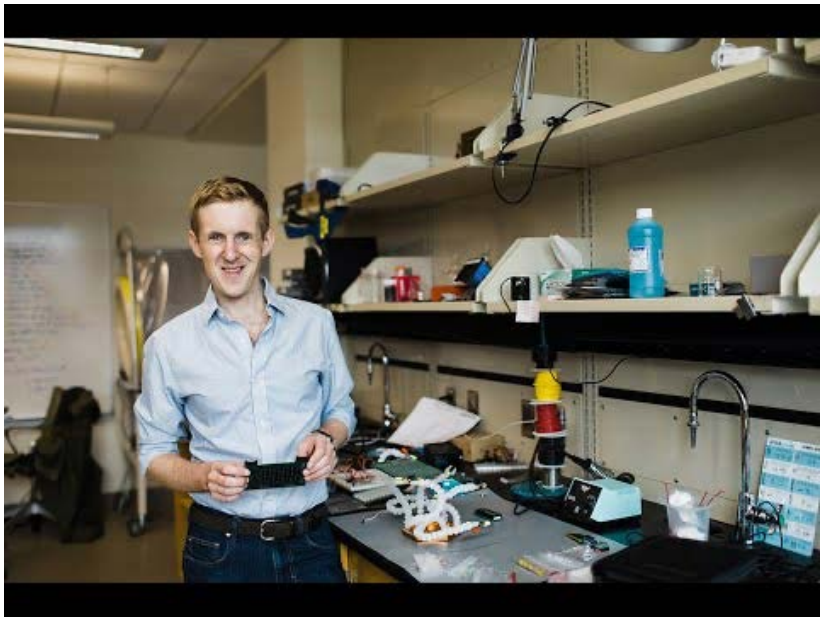
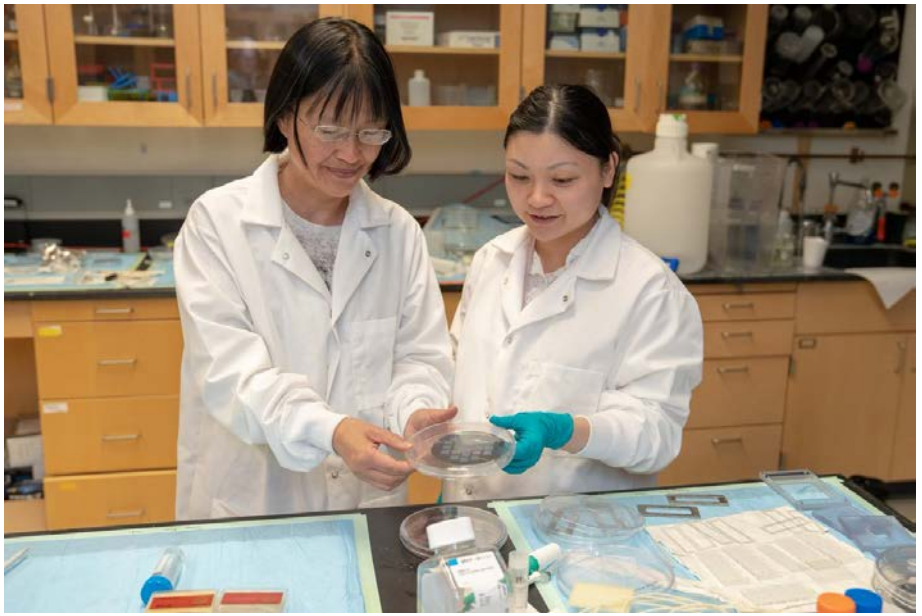


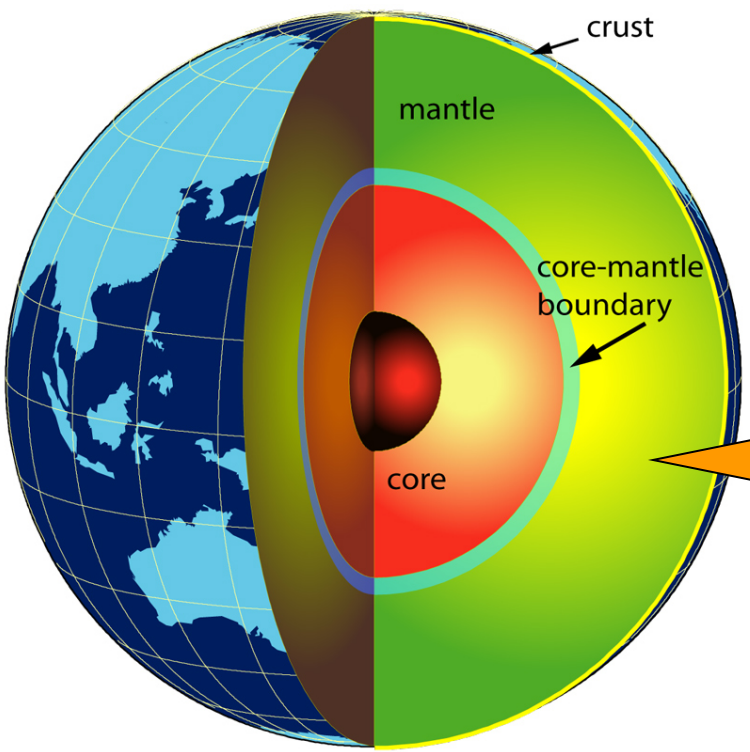
Buz Barstow, Cornell Biological and Environmental Engineering

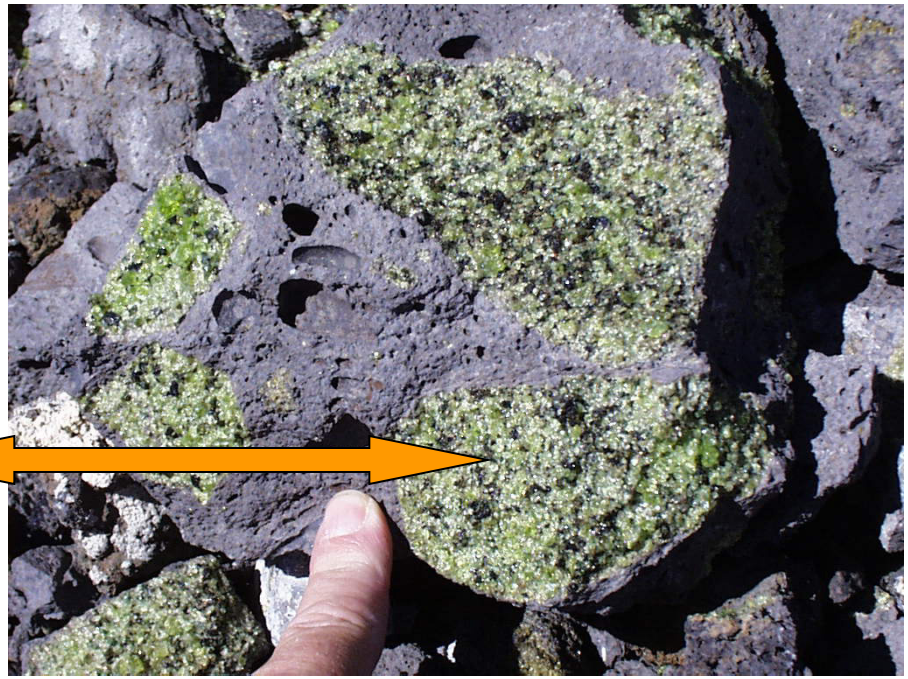


Mingming Wu, Cornell Biological and Environmental Engineering

Ricardo Sanchez-Murillo,
Stable Isotope Research Group National University of Costa Rica
(**Moving to UT Arlington**)

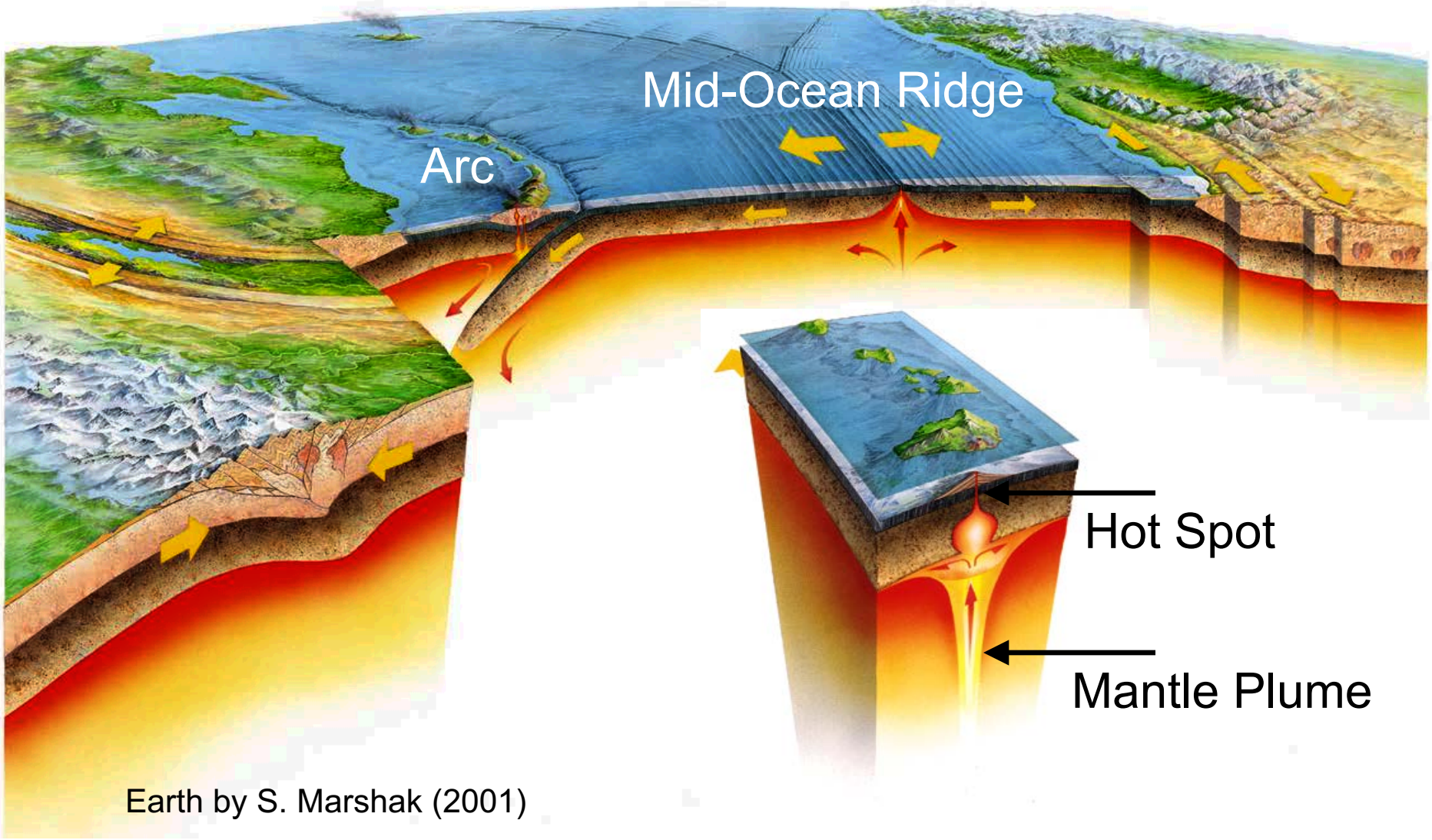
Earth's Mantle





Ultramafic rock: composed of >90% mafic (magnesium and ferric) minerals. Make most of Earth (and other rock planets) mantle. Most common mineral = olivine $(Mg,Fe)_2SiO_4$

Where does ultramafic rocks/peridotite forms?



Relative stability of igneous rock forming minerals during weathering

High stability	Quartz	
Increasing stability ↑	Muscovite	
	K-feldspar	
	Biotite	Albite
	Hornblende	Intermediate plagioclase compositions
	Augite	Anorthite
Low stability	Olivine	

KLEIN & PHILPOTTS_Tbl. 11.1

Crystallization order ↑

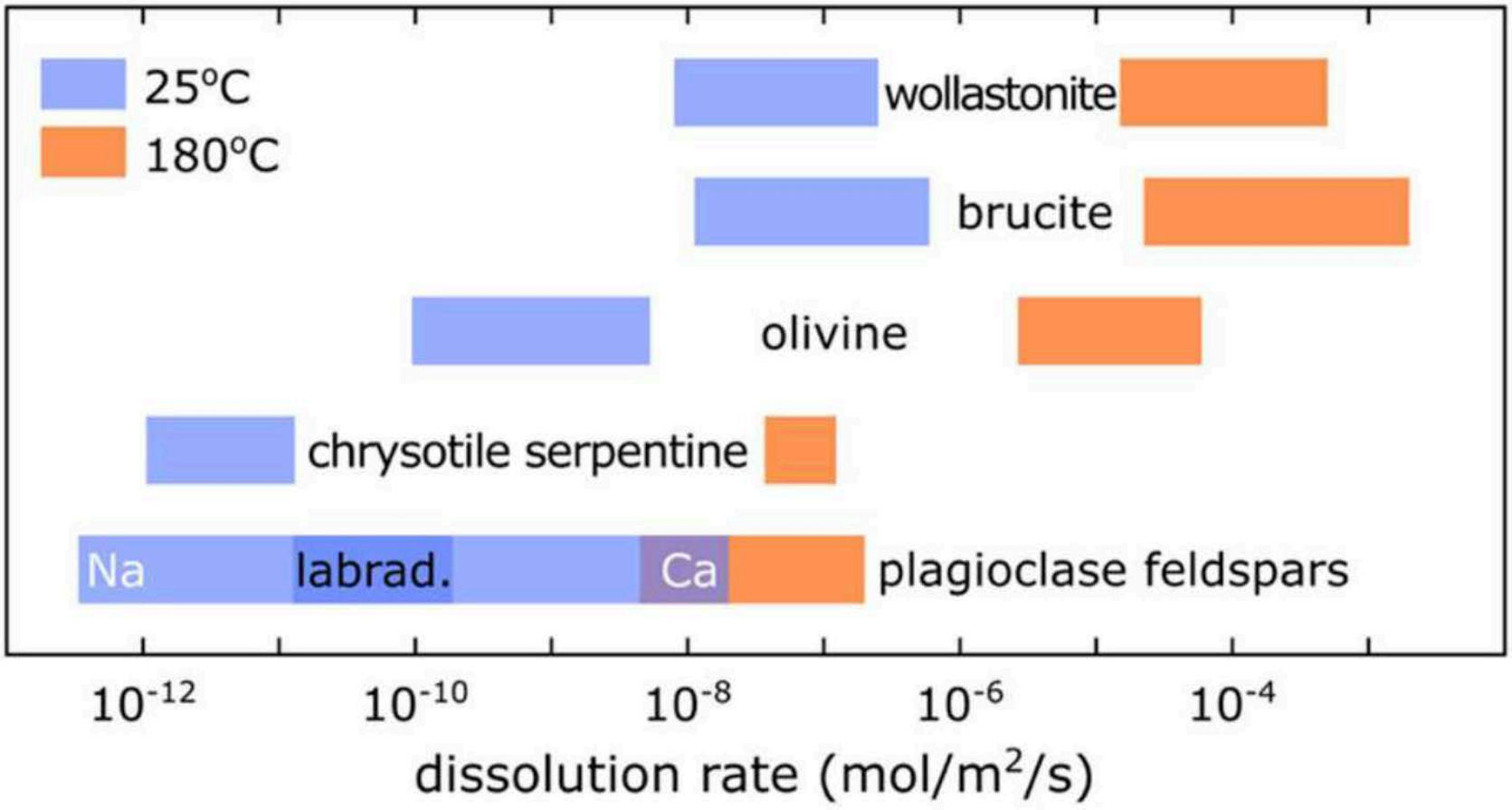
Peridotite-Basalt (olivine) → Andesite (Na-feld) → Rhyolite (qtz + k-feld)

$(Fe,Mg)_2SiO_4$

$NaAlSi_3O_8$

SiO_2

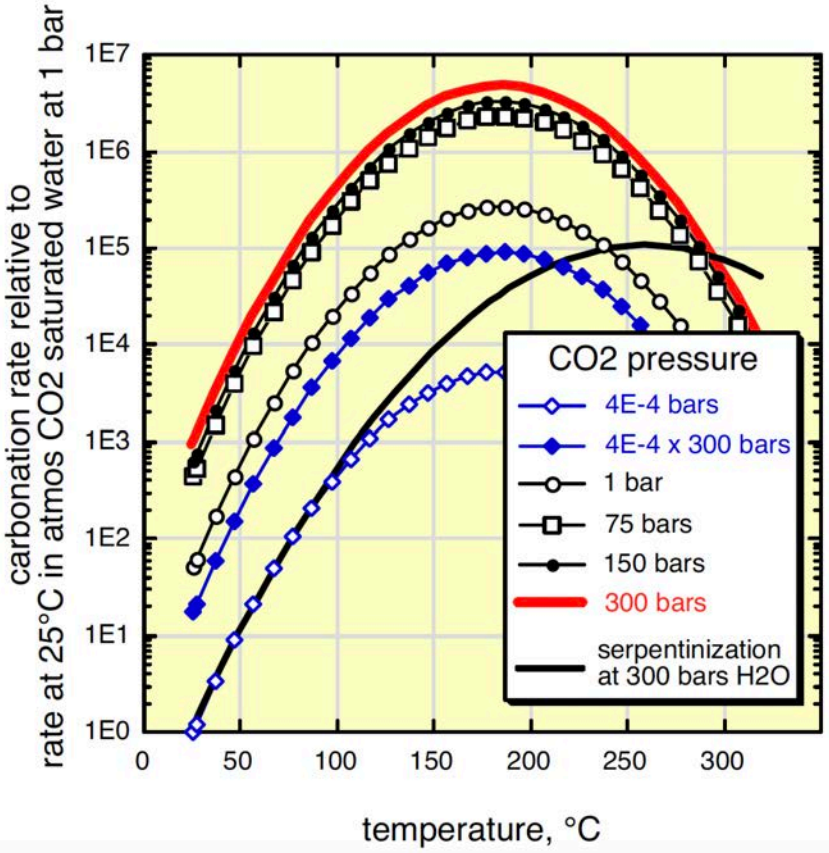
Natural Mineral Dissolution Rates



[Kelemen et al.,2019]

In situ carbonation of peridotite

$(Fe,Mg)_2SiO_4$ [olivine]+ nH_2O + **CO_2** → $Mg_3Si_2O_5(OH)_4$ [serpentine] + Fe_3O_4[magnetite] + **$MgCO_3$ [magnesite]** + SiO_2 [silica] + H_2(g)

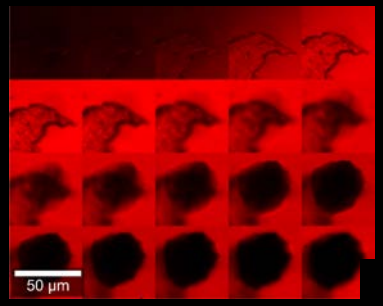


[Kelemen & Matter, PNAS, 2008]

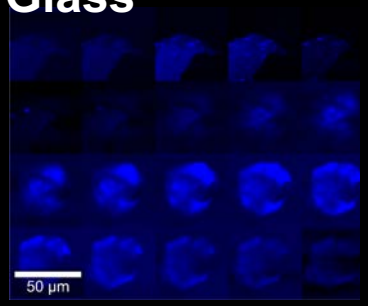
Liguria Ophicalcite (Carbonated Serpentinite), Deep Carbon Observatory

Raman 3D Map of in-situ carbonation in an olivine-hosted melt inclusion

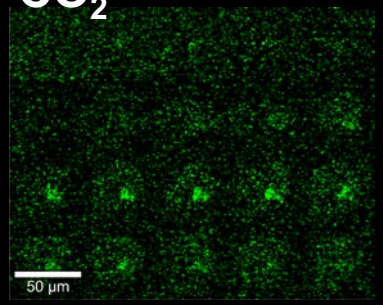
Olivine $(Mg,Fe)_2SiO_4$

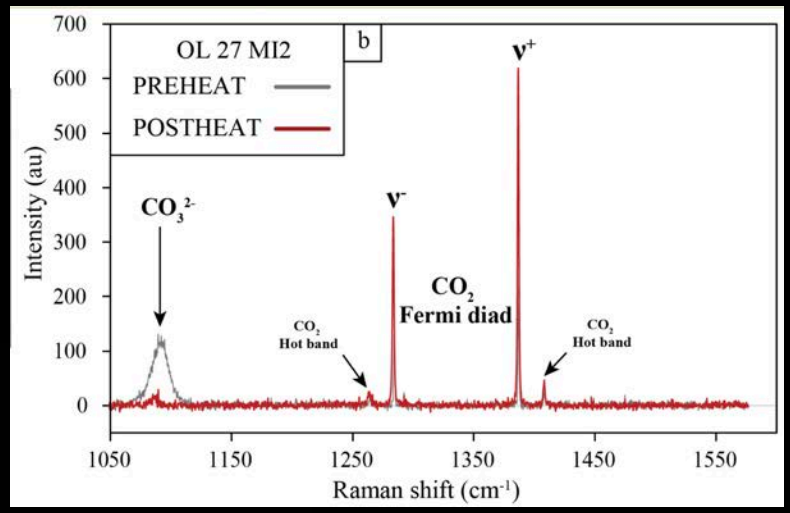


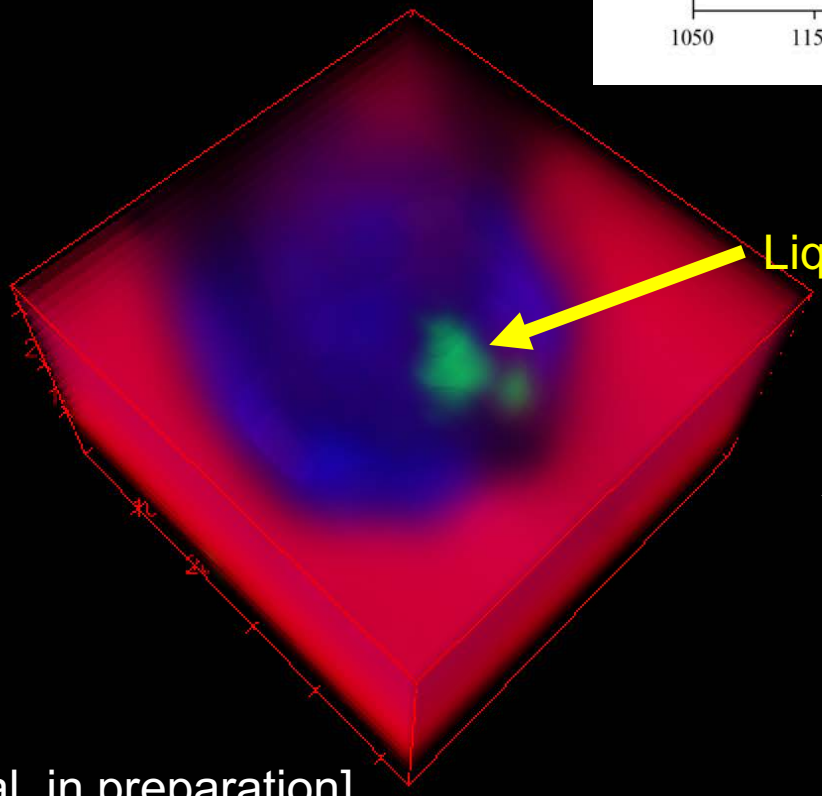
Glass



CO_2





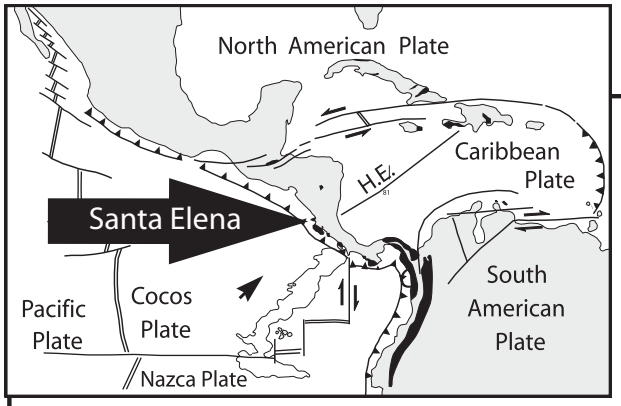


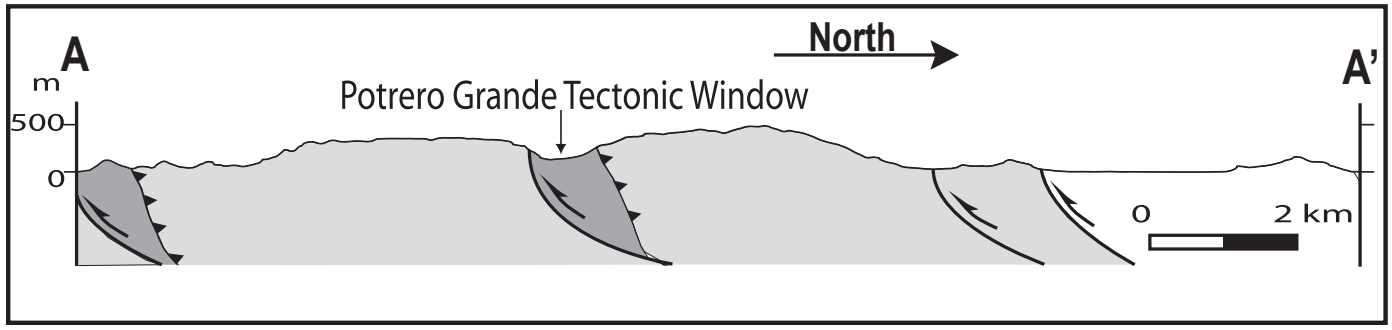
Liquid CO_2 (and carbonate)

XYZ stack scan:
55 µm x 55 µm x 35 µm
20 XY layers of 55 x 55 pixels
Integration time: 1 s per spectrum
Laser power: 9 mw

[DeVitre, Gazel, et al. in preparation]

The Santa Elena Ophiolite (Costa Rica)





Santa Elena Nappe

Pillow Basalts

Santa Rosa Accretionary Complex

Dike swarm

Dolerite dikes

Active serpentinization/carbonation in the Santa Elena Ophiolite

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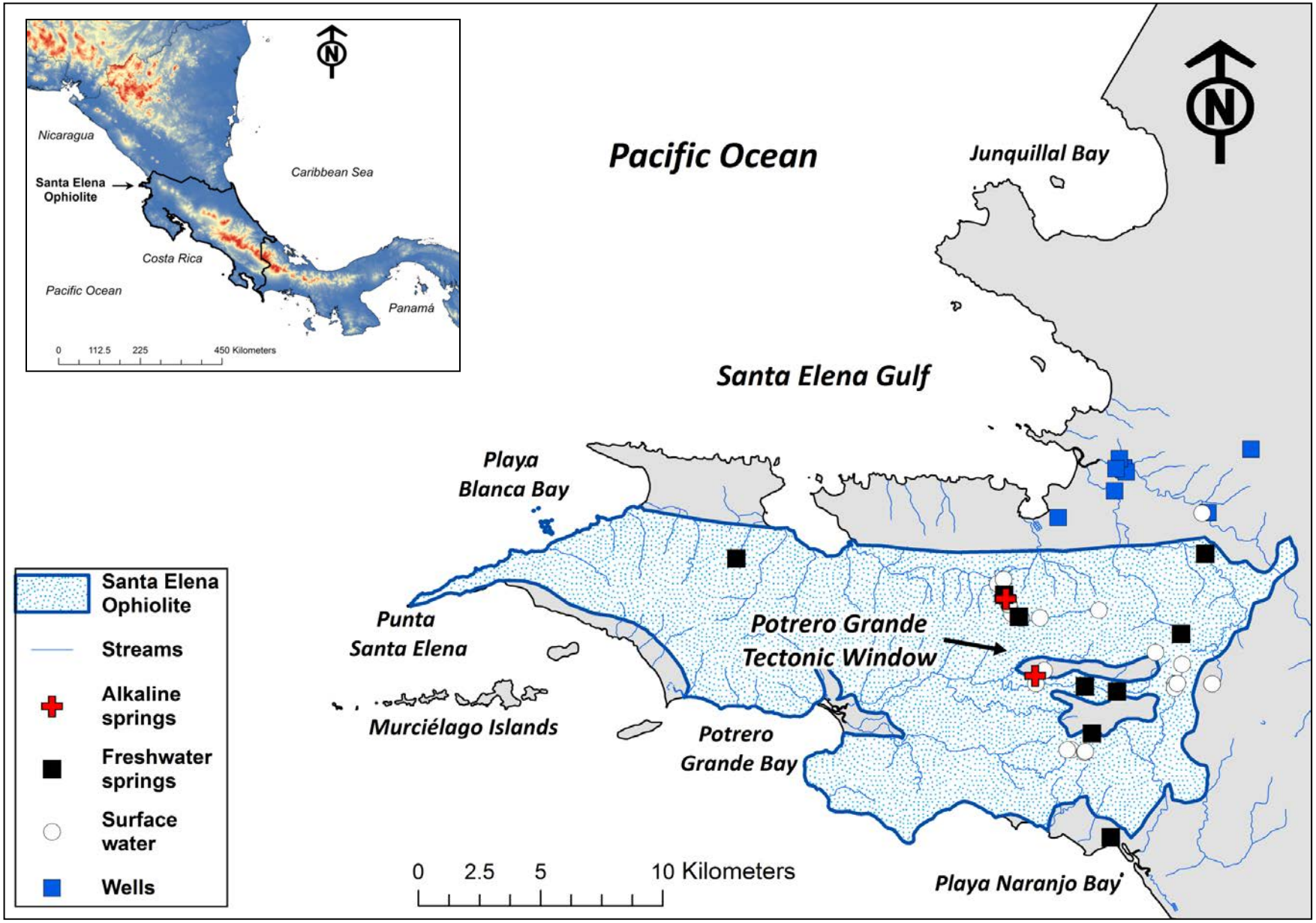
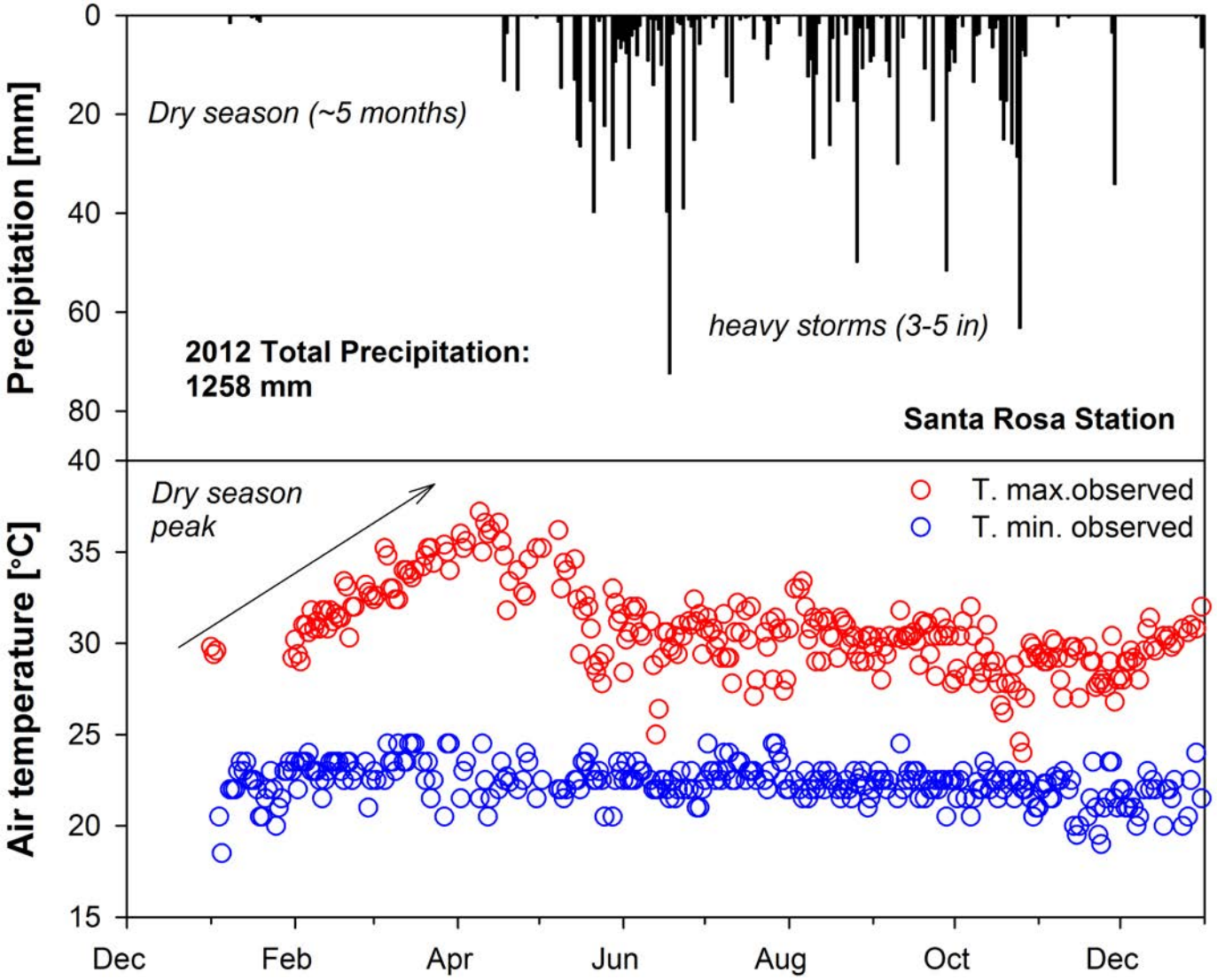
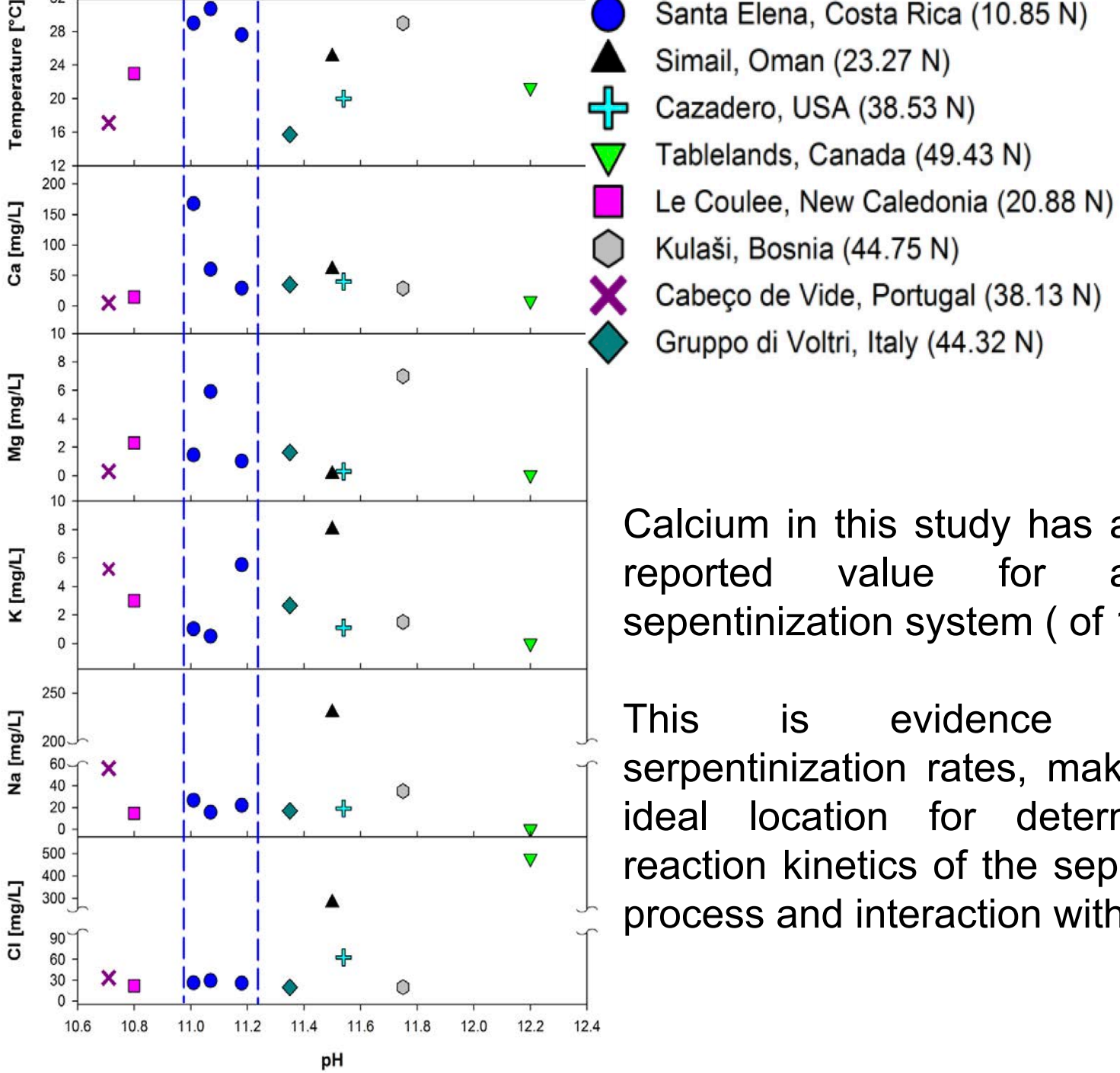


The Santa Elena system is sustained by recharge in the raining season



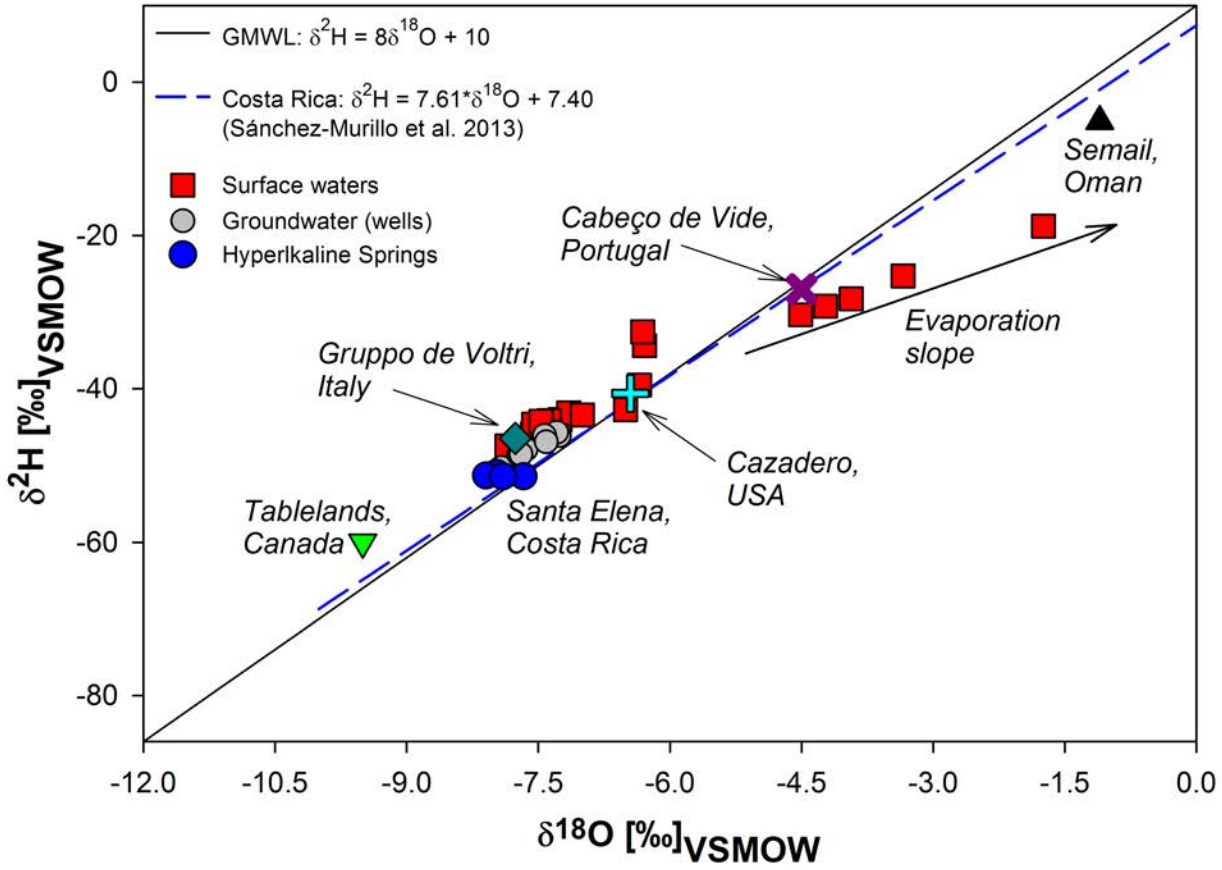
[Sanchez-Murillo, Gazel, et al., G-cubed 2014]



Calcium in this study has a maximum reported value for an active sepentinization system (of 167 mg/L).

This is evidence of high serpentinization rates, making this an ideal location for determining the reaction kinetics of the sepentinization process and interaction with life.

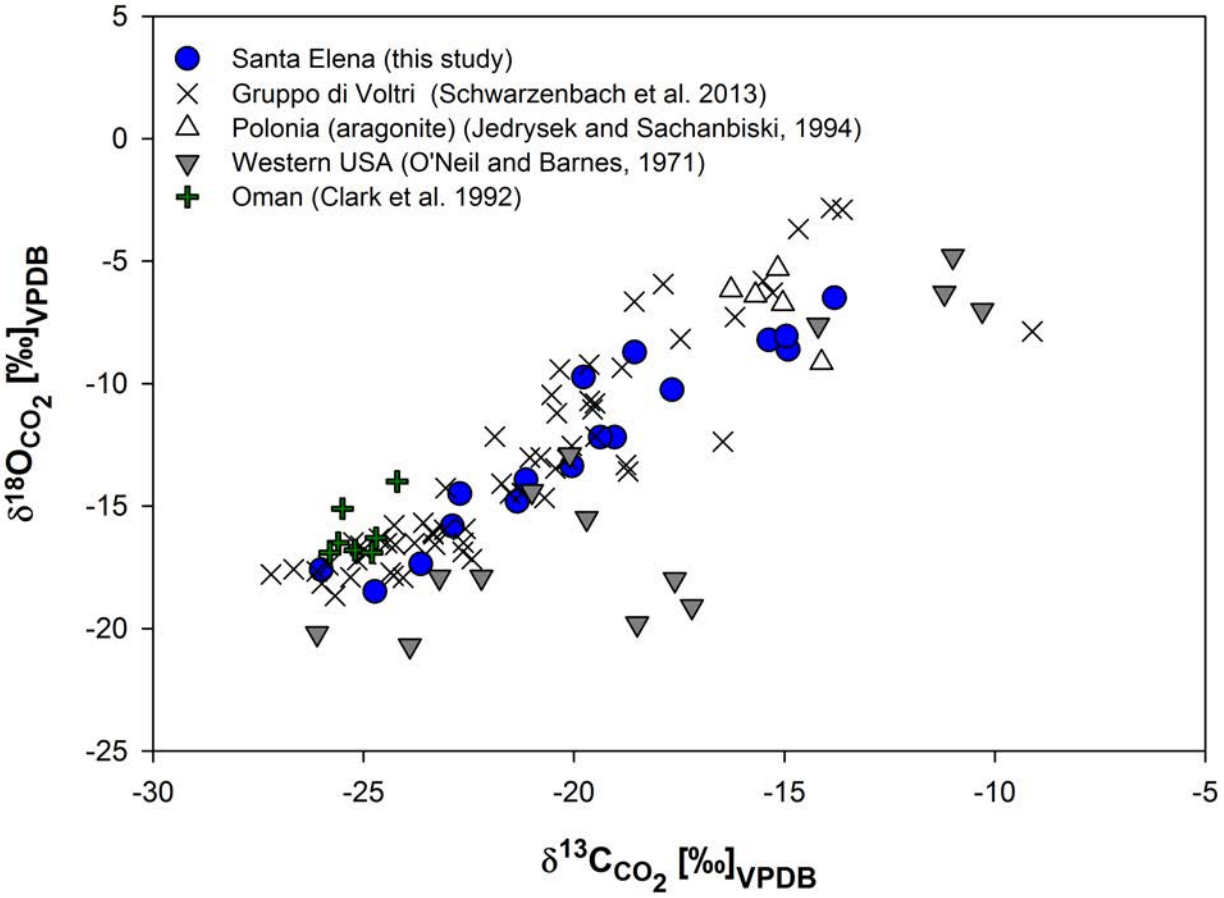
Active serpentinization/carbonation in the Santa Elena Ophiolite



Isotope composition of hyperalkaline fluids is remarkably similar to the GW signal, which supports the hypothesis that during prolonged dry periods these hyperalkaline springs are maintained by deep subsurface aquifers recharged during the rainy season.

[Sanchez-Murillo, Gazel, et al., G-cubed 2014]

Active serpentinization/carbonation in the Santa Elena Ophiolite



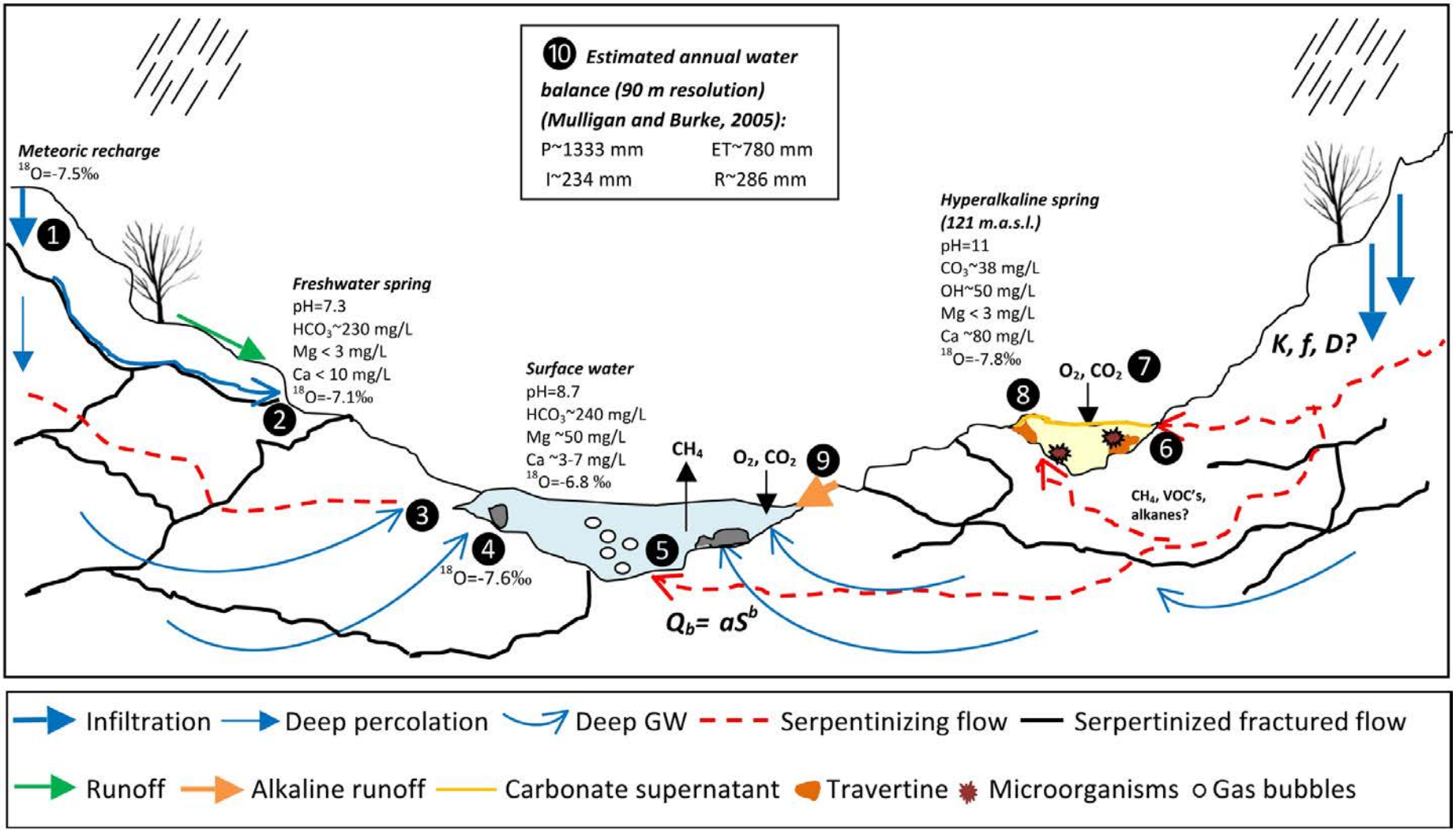
Santa Elena's carbon and oxygen isotope composition of carbonates is within the range of similar ultramafic-hosted carbonate deposits and suggests that the process of carbonation is strongly kinetically controlled but could be mediated by life.

[Sanchez-Murillo; Gazel, et al. G-cubed 2014]

Metabolisms related with active serpentinization in Santa Elena

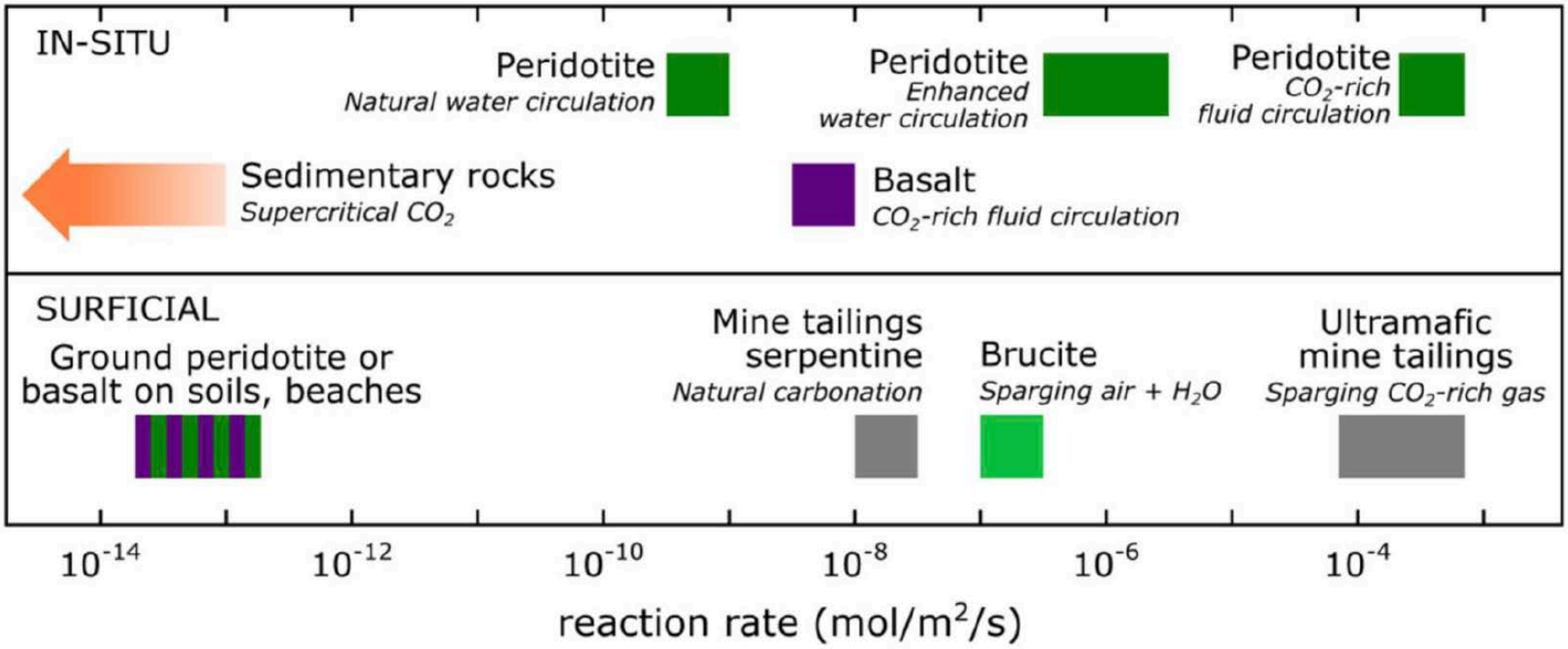
Division	Family;Genus	Metabolism	Murciélago Spring 8	Murciélago Spring 9	Danta Spring
Bacteria	Hydrogenophilaceae; Hydrogenophilus	Hydrogen oxidation	0.24	0.01	0.00
Bacteria	Rhodobacteraceae; Paracoccus	Hydrogen oxidation	0.18	0.02	0.00
Bacteria	Comamonadaceae; Hydrogenophaga	Hydrogen oxidation	8.10	19.82	3.21
Bacteria	Methylobacteriaceae; Meganema	Methane oxidation	0.12	0.00	0.00
Bacteria	Methylobacteriaceae; Methylobacterium	Methane oxidation	0.26	0.01	0.01
Bacteria	Comamonadaceae; Methylibium	Methanol oxidation	49.64	1.36	0.70
Archaea	Methanobacteriaceae;Methanobacterium	Methanogenesis	0.46	0.83	0.14
Archaea	Methanobacteriaceae; Methanobrevibacter	Methanogenesis	0.00	0.53	0.00
Archaea	Methanobacteriaceae; genus	Methanogenesis	0.00	3.75	28.87
Archaea	Methanocellaceae; Rice_Cluster_I	Methanogenesis	1.29	4.51	0.00
Archaea	Methanospirillaceae; Methanospirillum	Methanogenesis	0.01	6.79	0.00

Model for Active Serpentinization/Carbonation in the Santa Elena Ophiolite



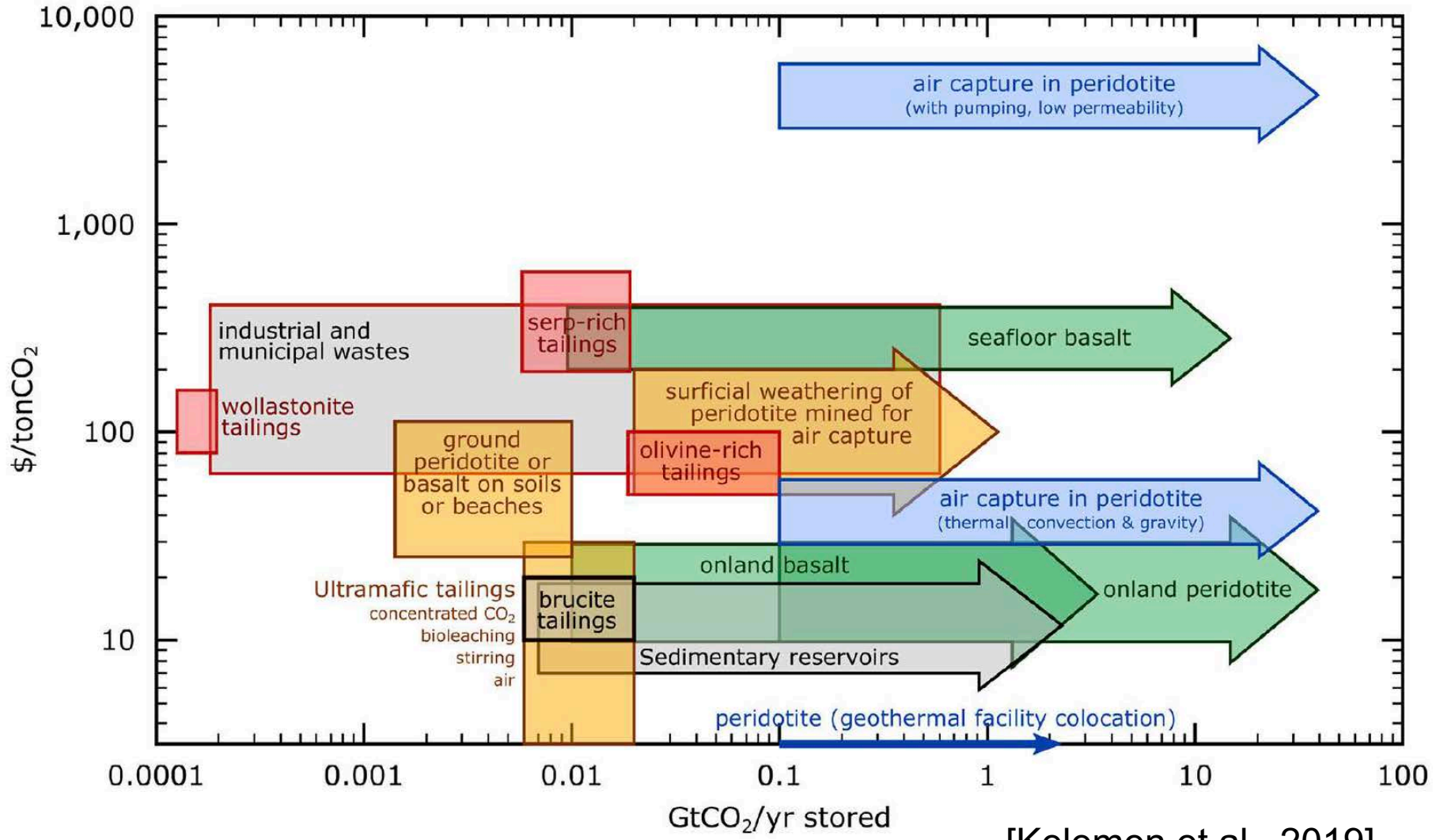
[Sanchez-Murillo; Gazel, et al., G-cubed 2014]

Carbonation Reaction Rates



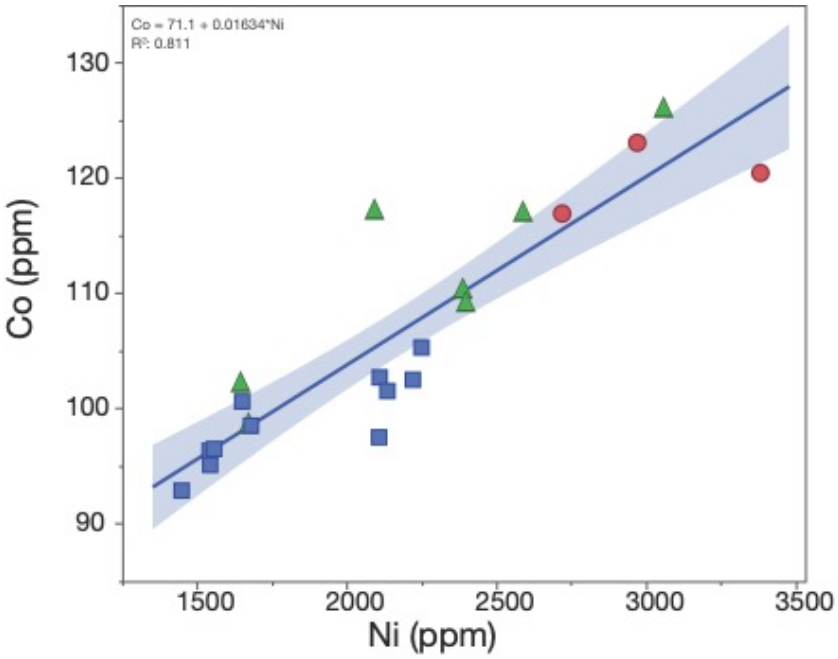
[Kelemen et al., 2019]

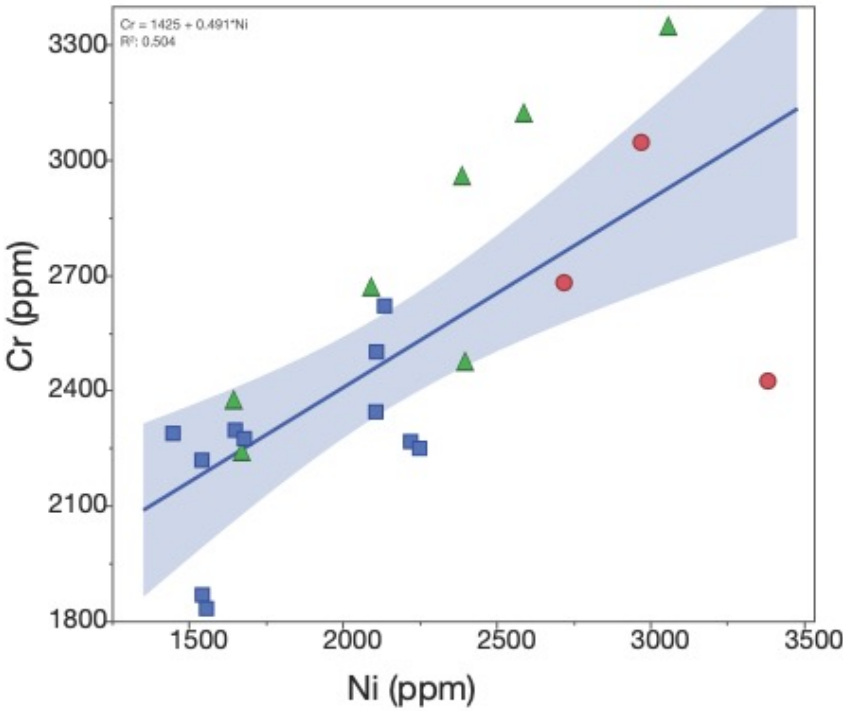
Cost of storing CO_2

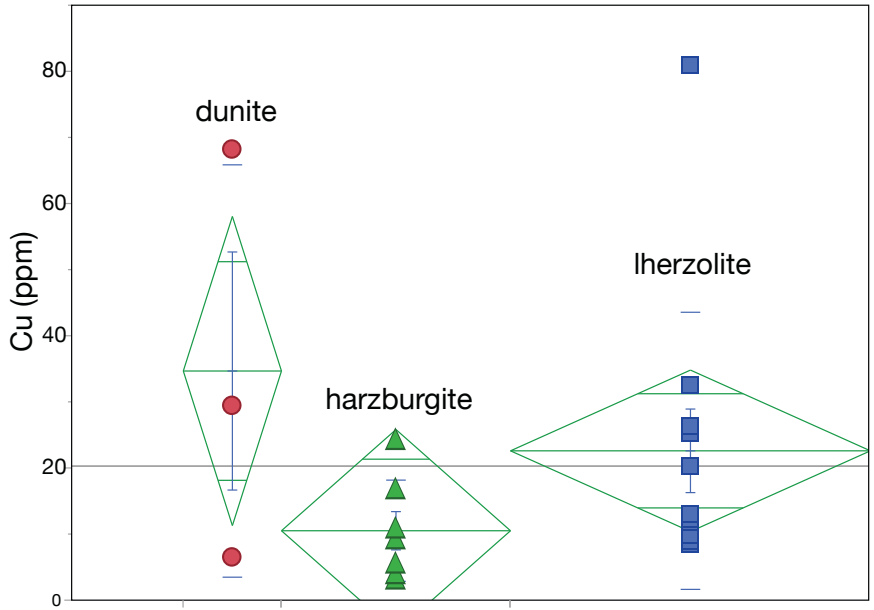


[Kelemen et al., 2019]

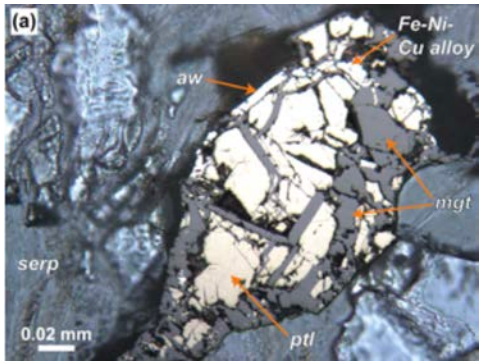
Potential for recovery of strategic metals



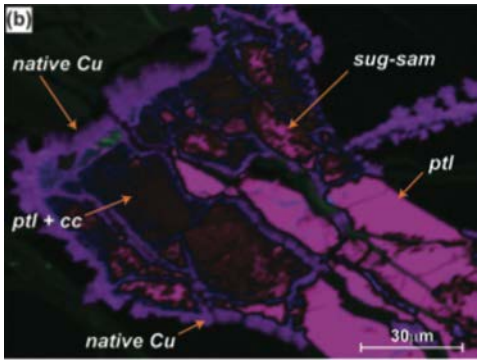




Fe-Ni-Cu alloy

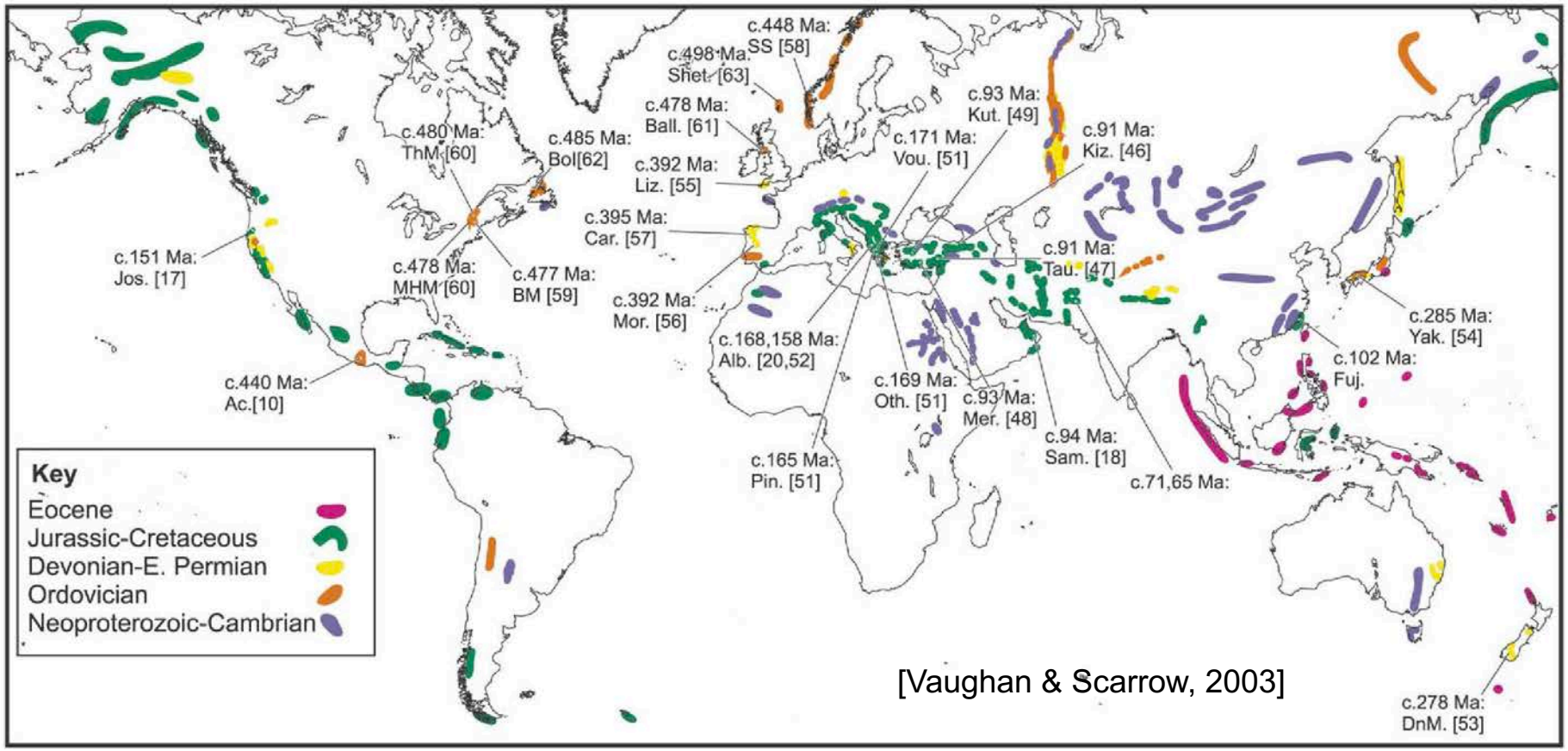


Native Cu and Pentlandite

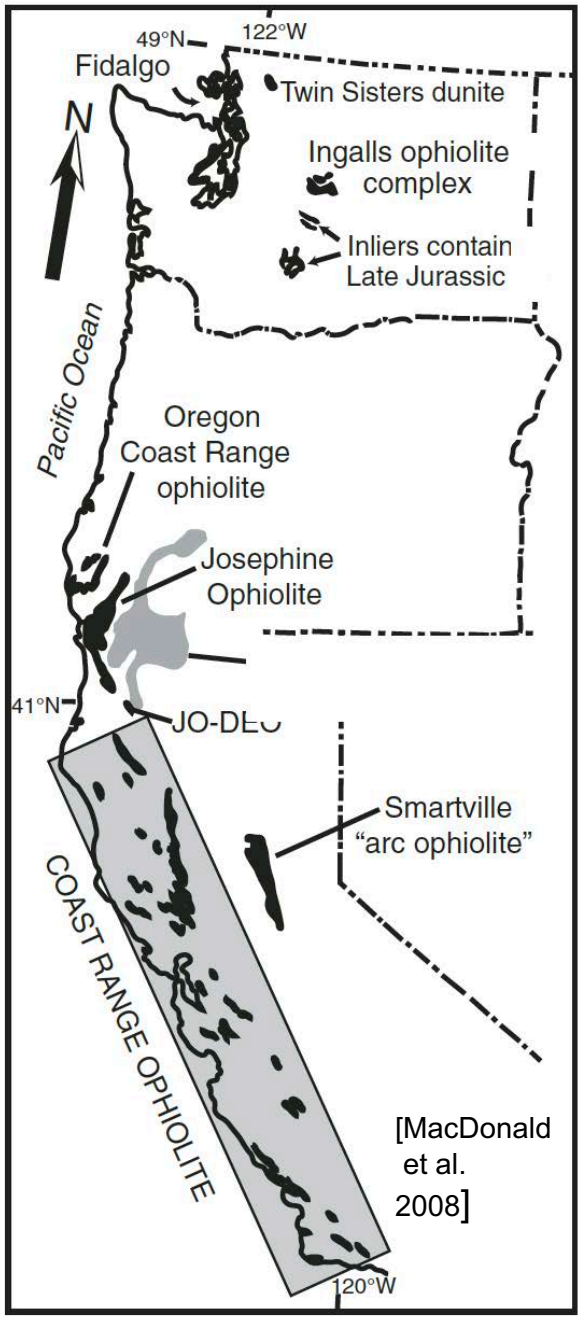


[Schwarzenbach, Gazel, & Caddick, 2014]

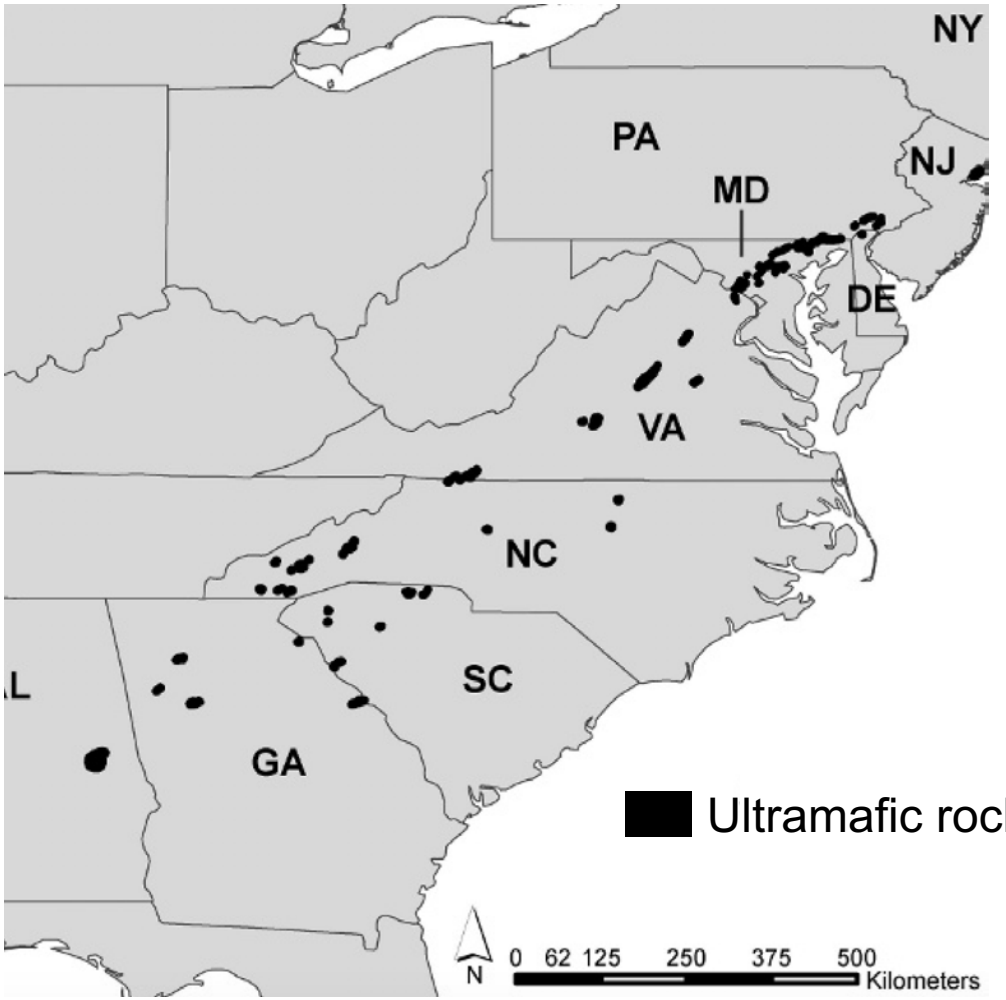
Where in the world we find ultramafic rocks?



Where in the US?



[MacDonald et al. 2008]



[East Coast, MacDonald et al., 2008; West Coast, USGS I-476]

Serpentinite, Staten Island (NY),

Serpentinite, Staten Island (NY) with carbonate veins